

# The Invariants of Self-Organizing Systems

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*Paper A — Cognitive Physics Series · Companion: Paper B, Cognition as a Self-Organizing System*

## Abstract

Some systems do something that appears to contradict basic physics: they maintain complex organized structure on their own, without external coordination, against the thermodynamic tendency toward disorder. Despite 75 years of work studying such systems across thermodynamics, information theory, dynamical systems, systems biology, and complex systems theory, a 2025 review in *npj Complexity* notes the field “still lacks the proper conceptual framework to understand it properly” (Gershenson, 2025). This paper provides that framework. We identify seven structural conditions — each established independently in its home discipline, the class named self-organizing systems since Ashby (1947) — that jointly constitute the necessary properties of any self-organizing system. The strongest evidence is not the conditions themselves but their repeated independent discovery: Conservation found in thermodynamics and information theory independently, Attractor Dynamics found in three separate fields by researchers who were not in contact. The conditions are not new. Their joint necessity across all classes of self-organizing systems is.

**Keywords:** self-organizing systems; complexity science; invariants; conservation law; attractor dynamics; coherence; symmetry protection; hierarchy; cybernetics; Noether symmetry; dissipative structures; cognitive physics

## 1. The Phenomenon

Some systems do something that shouldn’t be possible. They get more organized over time, on their own, without anyone organizing them. A cell doesn’t receive instructions on how to maintain itself. An ecosystem has no coordinator. A market

has no central planner. Yet all three produce order that a physicist would call improbable. The question is why some systems do this and most don't.

### **1.1 Three Examples**

A single biological cell contains hundreds of proteins performing specific functions simultaneously. Enzymes catalyze reactions. Ion pumps maintain electrical gradients. DNA replication machinery copies genetic information with extraordinary accuracy. Waste products are expelled. Energy is harvested and redistributed. All of this happens continuously, without instruction, through the dynamics of molecular interactions following chemical rules. Remove the energy supply and within minutes the organization collapses into equilibrium — the same disordered state as the surrounding environment. The organization was real, active, and self-maintained.

A tropical rainforest maintains stable species populations, nutrient cycles, and food webs across millions of interacting organisms. No organism coordinates the others. No central planner allocates resources. Each organism responds only to its immediate environment. Yet the global structure is stable, resilient, and remarkably organized when measured. It produces order across scales from soil microbes to canopy trees without any of its components having access to the global picture.

A financial market produces prices that coordinate the decisions of millions of buyers and sellers who have never met. No price-setter computes the right number. Local decisions aggregate into global signals. Remove the buyers and sellers and the price signal disappears instantly — just like the cell and the rainforest without their energy. The coordination was real. It was not designed.

### **1.2 What Makes These Systems Different**

Sand can form patterns — dunes, ripples, striations. But remove the wind and they erode. A cell compensates when conditions change. That's the difference. Not organized versus disorganized. Actively maintained versus passively shaped.

A designed machine also maintains organization — but it does so because a designer specified the target state and an engineer built the maintenance mechanism. The organization is imposed from outside. Self-organizing systems generate their own stable configurations. The cell, the ecosystem, the market: none of them have a designer.

This is the class of systems this paper addresses: those that generate and maintain organized structure through their own internal dynamics, without external coordination or design.

### 1.3 Why the Question Matters

The question — what these systems share that allows them all to do this — has been studied for 75 years across physics, biology, information theory, and economics. Researchers in each field found pieces of the answer. Nobody assembled them. Not because the pieces were hidden — they were in the literature, attributed to the researchers who found them — but because no one had asked whether they were jointly necessary across all classes simultaneously.

That question turns out to have a clean answer.

## 2. What Self-Organizing Systems Are

### 2.1 The Definition

The term ‘self-organizing system’ was coined by W. Ross Ashby in 1947 in the context of cybernetics (Ashby, 1947). The operational definition used here builds on that tradition: a self-organizing system is one that maintains ordered structure far from thermodynamic equilibrium, through internal dynamics rather than external coordination, by continuously exchanging energy and information with its environment, and exhibiting attractor behavior — stable configurations the system tends toward after perturbation.

#### DEFINITION

**Self-organizing system** — maintains ordered structure far from equilibrium through internal dynamics, not external design, by exchanging energy and information with its environment and returning to attractors after perturbation (Ashby, 1947).

This is operational, not philosophical. It is testable. The definition is precise enough to exclude systems that look similar but don’t qualify. Three classes are commonly confused with self-organizing systems:

- **Crystals at equilibrium** — organized but passive. Maintained by thermodynamic stability, not active dynamics. No active maintenance.
- **Designed machines** — organized but externally maintained. The target was specified by a designer. Self-organizing systems generate their own stable configurations; machines maintain externally specified ones.
- **Chaotic systems** — active dynamics but no stable attractors. Organization appears momentarily but cannot be sustained against perturbation.

### 2.2 Six Canonical Classes

Six classes of self-organizing systems are well-established in the scientific literature. They are presented here for a specific reason: to show that whatever structural

conditions these systems share cannot be specific to any physical substrate. Cells, markets, and convection cells share nothing physically. Any property they all have must be a structural requirement, not a physical one. These six classes are the evidence base for that claim.

Consider how different these actually are. A Bénard cell is heated fluid. A cell is biochemistry. An ecosystem is millions of organisms interacting. A market is human decisions. No shared components. No shared mechanisms. No shared evolutionary history. All doing the same thing.

| Class                                    | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dissipative Structures and Synergetics   | Bénard convection cells, chemical oscillators, reaction-diffusion patterns, laser physics. Prigogine's dissipative structures (Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984) and Haken's synergetics (Haken, 1975; 1983) were developed as two independent mathematical frameworks for the same phenomenon — self-organization in open systems far from equilibrium. Prigogine focused on entropy production and attractor formation; Haken on cooperative phenomena and order parameters. Both are required for a complete picture.                                                            |
| Biological Systems Including Autopoiesis | Cells, organisms, immune systems, developmental processes. Maturana and Varela formalized autopoiesis — self-production — as the defining property of living self-organizing systems: those that produce and maintain their own components and boundary through their own dynamics (Maturana & Varela, 1974; 1980). Kauffman's work on Boolean networks established the coherence requirements of biological regulatory networks (Kauffman, 1969; 1993).                                                                                                                                                 |
| Ecological Systems                       | Food webs supporting thousands of species, nutrient cycles spanning continents, predator-prey dynamics maintaining stable populations across millions of organisms — all without a coordinator. No organism has access to the global picture. Each responds only to its local environment. The organized structure emerges from those local interactions and is maintained through feedback dynamics. Remove a keystone species or disrupt a nutrient cycle and the system reorganizes around the loss — demonstrating active maintenance, not passive stability. (Odum, 1953; MacArthur & Wilson, 1967) |
| Social and Economic Systems              | Markets, language evolution, norm emergence, institutional development. Price signals emerge from distributed individual decisions without any coordinator computing the right price. Grammatical structure emerges from distributed language use without any grammarian designing it. Hayek (1945) established markets as the canonical case of self-organizing knowledge coordination. Schelling (1978) extended this to social coordination more broadly.                                                                                                                                             |

| Class                                  | Description                                                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Developmental and Regenerative Systems | Morphogenesis, regeneration, wound healing. A salamander regrows a lost limb using only the local information available to its cells. The target configuration is an attractor the system's dynamics converge to, not an external specification. (Turing, 1952)                                                                                                                        |
| Critical Systems                       | Systems with slow driving and fast relaxation spontaneously evolve to critical states — the boundary between order and chaos — producing power-law distributions. The sandpile model is the canonical demonstration: grains added one at a time eventually produce avalanches of all sizes, with no external coordination producing the critical state. (Bak, Tang & Wiesenfeld, 1987) |

These six classes share nothing physically. That question has been answered piece-meal across them: Prigogine identified attractor dynamics and entropy production, Haken identified coherence through order parameters, Shannon identified conservation and quantization, Simon identified hierarchy, Maturana and Varela identified self-production. What has not been done is assembling these into a jointly necessary minimal set applicable across all classes — showing that what each researcher found in their own system is a condition required by all of them. That is what Section 3 presents.

### 3. The Seven Invariants

What follows hasn't been assembled before. Each of these conditions exists in its home field. Physicists know about Conservation. Complex systems researchers know about Hierarchy. Information theorists know about Quantization. Nobody put them together as a set and asked: are these jointly necessary for any self-organizing system, across all classes?

The cross-domain examples below show each condition appearing in multiple unrelated systems — evidence that these are structural requirements, not artifacts of any particular field.

#### **1. Conservation — outputs must account to inputs.**

*Thermodynamics and Information Theory · Clausius (1850, 1865); Shannon (1948)*

Clausius proved that energy cannot be created or destroyed — outputs must account to inputs. Shannon proved the information-theoretic parallel: entropy is conserved across lossless transforms. Both results share the same logical structure: organized systems cannot produce more than they consume. The accounting is not optional; it is the condition under which outputs can be traced and trusted.

**Cross-domain:** Thermodynamic cycles, energy balance in metabolism, metabolic stoichiometry, budget constraints in markets, Shannon entropy bounds on compression.

*Without it:* the system produces without accounting. Outputs cannot be traced to inputs. No distinction between organized output and random generation.

## **2. Continuity — organized structure evolves without discontinuous jumps.**

*Dynamical Systems Theory · Poincaré (1890s); synthesized in Strogatz (1994)*

The principle that physical systems evolve through continuous state trajectories was established through Poincaré’s late 19th century work on dynamical systems. The state at time  $t+\delta$  is connected to the state at  $t$  through a path. Discontinuous transitions are destabilizing events, not normal operation. Waddington (1957) independently formalized continuous state evolution in developmental biology through canalization — developmental trajectories follow continuous paths buffered against perturbation, derived entirely from embryology without reference to dynamical systems theory.

**Cross-domain:** Continuous trajectories in phase space, developmental canalization (Waddington, 1957), embryogenesis proceeding through causally connected stages, evolutionary gradualism, price continuity in markets.

*Without it:* the system loses the thread of its own organization. Prior organized state has no causal connection to current state. Structure cannot accumulate.

## **3. Quantization — stable states are discrete.**

*Information Theory and Molecular Biology · Shannon (1948); Crick (1958)*

Shannon demonstrated that reliable communication and storage require discrete stable states. The bit is 0 or 1, not 0.73. Crick (1958) independently derived the same structural requirement from molecular biology: the genetic code is discrete, with each codon a fixed three-nucleotide combination mapping to exactly one amino acid. Crick was not applying Shannon — he was solving a biological problem and arrived at the same conclusion.

**Cross-domain:** Binary encoding and error correction in information theory, genetic discreteness in biology (four bases, discrete codons), discrete protein folding conformations, quantum energy levels, discrete transactions in markets.

*Without it:* there is no error correction. Small deviations compound rather than snap back. Perturbations amplify indefinitely.

#### **4. Coherence — components cannot simultaneously pursue contradictory goals.**

*Systems Biology, Cybernetics, and Ecology · Kauffman (1969; 1993); Ashby (1956); Gause (1934)*

Kauffman demonstrated that metabolic networks require mutual consistency among components — contradictory pathways produce cell death, not compromise. Ashby (1956) independently derived the same requirement from cybernetics through the Law of Requisite Variety: a regulatory system whose components pursue contradictory responses cannot stably regulate. Gause (1934) proved the ecological parallel — competitive exclusion: two species cannot stably occupy the identical ecological niche simultaneously. Three independent fields. Same structural requirement.

**Cross-domain:** Metabolic pathway coherence in biology, Law of Requisite Variety in cybernetics (Ashby, 1956), competitive exclusion in ecology (Gause, 1934), quantum decoherence in physics, institutional incoherence causing organizational fragmentation.

*Without it:* a system whose components pursue contradictory goals expends energy fighting itself. The contradiction does not resolve into synthesis. It produces system failure.

#### **5. Entropy Production and Attractor Dynamics — motion converges toward stable organized states.**

*Dissipative Structures and Synergetics · Nicolis & Prigogine (1977); Prigogine & Stengers (1984); Haken (1975; 1983)*

Prigogine showed that far-from-equilibrium systems maintain organization through attractor dynamics that pull system trajectories toward stable organized configurations. Haken's synergetics independently formalized this through order parameters — slow attractor variables that enslave fast variables in cooperative systems. Two independent mathematical frameworks, same structural property. Without attractor dynamics, energy flow produces only dissipation.

**Cross-domain:** Bénard convection and Belousov-Zhabotinsky reaction (Prigogine), order parameters in laser physics and neural networks (Haken), morphogenetic attractors in development (Turing, 1952), convergent evolution (Conway Morris, 2003), self-organized criticality (Bak et al., 1987), market equilibria as attractors.

*Without it:* a self-organizing system would generate continuous novelty without ever stabilizing. Every perturbation produces a new trajectory. Nothing persists.

## 6. *Symmetry Protection — stable configurations resist arbitrary change.*

*Mathematical Physics and Developmental Biology · Noether (1918); Waddington (1957); Maturana & Varela (1974; 1980)*

Noether proved that every conservation law corresponds to a symmetry protecting a conserved quantity from arbitrary change. Waddington (1957) independently derived the same structural requirement from developmental biology through canalization — developmental pathways are buffered against perturbation, actively resisting displacement from the organized trajectory. Maturana and Varela (1974; 1980) further established biological self-maintenance as a third independent derivation: living systems produce and maintain their own boundary, actively protecting the organized state from dissolution.

**Cross-domain:** Conservation of momentum, energy, and charge in physics (Noether, 1918), developmental canalization (Waddington, 1957), autopoiesis as organized self-production (Maturana & Varela), genetic fidelity through DNA error-correction, institutional inertia in stable social systems.

*Without it:* stable configurations can be arbitrarily changed. Prior organized state is overwritten at the first perturbation. No memory, no accumulation.

## 7. *Hierarchy — stable complex organization builds from stable simpler layers.*

*Complex Systems, Ecology, and Software Engineering · Simon (1962); O’Neill et al. (1986); Parnas (1972)*

Simon showed through systematic observation that all stable complex systems exhibit hierarchical composition — each level depends on the stability of the level below. O’Neill et al. (1986) independently derived the same structural requirement from ecology: organization results from differences in process rates, with each level having its own controls and stability, hierarchical structure emerging from dynamic stabilization at lower levels. Parnas (1972) derived it from software engineering: complex systems must be decomposed into modules that hide their implementation details, building higher-order functionality on stable lower-level interfaces.

**Cross-domain:** Atomic → molecular → macroscopic structure in physics, genetic → cellular → tissue → organ → organism in biology, ecological hierarchy from process rate differences (O’Neill et al., 1986), modular software architecture (Parnas, 1972), evolution through stable intermediates (Maynard Smith & Szathmáry, 1995).

*Without it:* complex organization cannot persist at scale. No level can rely on the stability of the one below.

Seven conditions. Each established in its home discipline. Each necessary. Each present across all six canonical classes. Section 4 asks whether together they constitute a complete and minimal set.

**NOTE**

**A Note on the Assembly**

These seven conditions have not previously been assembled as a unified necessary set. The cross-class assembly is the contribution: the claim that these seven, jointly, are the minimal necessary conditions for any self-organizing system — across all six canonical classes, not just the class each researcher was studying. The conditions are not new. Their joint necessity across all classes is.

Conservation and Quantization are both grounded in Shannon (1948). This is intentional. Shannon’s 1948 paper simultaneously establishes that information must be conserved and represented in discrete stable states. Independent requirements sharing one source. The numbering reflects historical discovery order, not hierarchy of importance. All seven are jointly necessary.

**4. Why All Seven Are Necessary**

Remove any one condition and self-organization fails in a specific, identifiable way. Not a general degradation — a precise failure that corresponds to exactly the condition removed.

Each row in the table below is independent. The failure of one condition is different from the failure of any other. A system that satisfies six conditions but violates one does not exhibit partial organization. It exhibits the specific failure of the violated condition, with no compensating mechanism.

| Condition Removed | Failure Mode                       | Why It Fails                                                                                                                               |
|-------------------|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Conservation      | Output decouples from input        | The system produces without accounting. Outputs cannot be traced to inputs. No distinction between organized output and random generation. |
| Continuity        | Organization cannot accumulate     | State becomes disconnected across time. Prior organized state has no causal force on current state. The system cannot build on itself.     |
| Quantization      | Perturbations amplify indefinitely | No error correction. Small deviations compound rather than snap back. Organization drifts rather than stabilizing.                         |

| Condition Removed   | Failure Mode                       | Why It Fails                                                                                                                                          |
|---------------------|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Coherence           | System destroys itself from within | Components pursue contradictory goals. Energy is expended fighting internal contradictions rather than maintaining organized structure.               |
| Attractor Dynamics  | Organization never stabilizes      | Motion generates without converging. Every perturbation produces a new trajectory. Nothing persists long enough to constitute organized structure.    |
| Symmetry Protection | Organized state is not protected   | Stable configurations can be arbitrarily changed. Prior organized state is overwritten at the first perturbation. No memory, no accumulation.         |
| Hierarchy           | Complexity cannot persist at scale | Higher-order organization built on shifting foundations. No level can rely on the stability of the one below. Complex structure cannot be maintained. |

This isn't a proof. It's an empirical observation: no known self-organizing system requires a condition beyond these seven, and every known failure of self-organized structure traces to at least one of them being violated. That's not deductive certainty — but it's a strong pattern across every class examined.

*The strongest evidence that these seven are the right conditions comes not from the necessity argument above but from what happened across the scientific literature: they kept getting found independently.*

#### COUNTERPOINT

This is not a deductive proof. It is an empirical pattern: no known self-organizing system requires an eighth condition, and every known failure traces to at least one of these seven being violated.

## 5. The Independent Convergences

Here's what's interesting about these seven conditions: several of them were discovered independently, in different fields, by researchers who weren't in contact with each other. Same condition. Different systems. Different methods. Different cen

turies. That convergence is the strongest evidence in this paper. It means these conditions aren't a framework someone chose. They kept getting found.

#### EVIDENCE

Conservation, attractor dynamics, and hierarchy were each found independently in separate fields by researchers who were not in contact. The conditions kept getting found; they were not chosen as a framework.

Each sub-heading below uses the exact condition name from Section 3. All seven conditions have documented independent discovery across multiple unrelated fields.

### Conservation — Found Independently Three Times

Clausius (thermodynamics, 1850) and Shannon (information theory, 1948) both found that organized systems conserve — energy in one case, information entropy in the other. The mathematical structure is the same. Two independent derivations of the same conservation principle in physically different domains.

A third independent convergence comes from dissipative structures. Prigogine (1977) found that far-from-equilibrium systems maintain organization through continuous input-output accounting of entropy — the system must continuously consume free energy to maintain its organized state. A dissipative structure is a system that maintains organized form by continuously dissipating energy — consuming inputs to pay the ongoing thermodynamic cost of its own organization. Prigogine showed this is not an exception to Conservation but its operating expression at the systems level. Three communities. Three formalisms. Same requirement.

#### DEFINITION

**Dissipative structure** — organized form maintained by continuously consuming free energy to pay the thermodynamic cost of its own order (Prigogine, 1977).

### Continuity — Found Independently Twice

The principle of continuous state evolution was established through Poincaré (1890) in his work on dynamical systems — physical systems evolve through connected paths in phase space.

Waddington (1957) independently derived the same structural requirement from developmental biology through canalization: developmental trajectories follow continuous buffered paths, each stage causally connected to the prior. Canalization is the tendency of developmental processes to follow established trajectories even when genetically or environmentally perturbed — the embryo finds its way back to the normal developmental path. This buffering requires continuous state evolution

as its structural prerequisite. Waddington derived this from embryological observation, not from dynamical systems mathematics. Turing's (1952) reaction-diffusion equations for morphogenesis further formalize continuous state dependence in development — the pattern at each developmental moment depends causally on the continuous prior state.

Two independent fields — dynamical systems mathematics and developmental biology — both found that organized systems cannot tolerate discontinuous jumps in their state evolution.

### **Quantization — Found Independently Three Times**

Shannon (information theory, 1948) found that reliable information requires discrete states. Planck (1900) and Bohr (1913) found that energy is quantized in quantum mechanics. These are mechanistically different but structurally convergent: both found that stable states at the relevant scale are discrete, not continuous.

Crick (1958) provided a third independent derivation from molecular biology. Solving the problem of how genetic information is reliably transmitted, Crick established that the genetic code is discrete — each codon a fixed three-nucleotide combination mapping to exactly one amino acid. Crick was not applying Shannon. He was deriving from biochemistry what Shannon had derived from communication theory: reliable transmission requires discrete stable states. Three communities. Same structural requirement.

### **Coherence — Found Independently Three Times**

Kauffman (systems biology, 1969; 1993) demonstrated that biological regulatory networks require mutual consistency among components — contradictory metabolic pathways produce cell death, not compromise.

Ashby (cybernetics, 1956) independently derived the same requirement through the Law of Requisite Variety: a regulatory system must have variety matching the variety of disturbances it faces, meaning its components cannot simultaneously pursue contradictory responses. Variety in this context means the number of distinct states a system can occupy. Ashby's law states that a regulator must have at least as much variety as the disturbances it faces — and critically, its components cannot simultaneously produce contradictory regulatory responses, or the system fails to regulate at all. Ashby arrived at this from control theory, not from biology.

Gause (ecology, 1934) proved the competitive exclusion principle: two species cannot stably occupy the identical ecological niche simultaneously. Contradictory goals at the ecosystem level cannot be simultaneously sustained. Three communities. Three entry points. Same structural requirement.

**Attractor Dynamics — Found Independently Three Times**

Prigogine (dissipative structures, 1970s): far-from-equilibrium physical systems converge to organized attractor states through entropy production. The Bénard cell is the canonical demonstration.

Haken (synergetics, 1970s–80s): order parameters in cooperative systems act as attractors, enslaving fast variables. An independent mathematical framework from Prigogine’s, arriving at the same structural property from laser physics and neural networks.

Conway Morris (convergent evolution, 2003): independent evolutionary lineages converging on the same biological solutions — eyes, wings, echolocation — demonstrate attractor dynamics in fitness landscapes. Three communities. Three frameworks. Same property.

**Symmetry Protection — Found Independently Three Times**

Noether (mathematical physics, 1918): every conservation law corresponds to a symmetry protecting a conserved quantity from arbitrary change. The mathematical proof that stable configurations have structural protection.

Waddington (developmental biology, 1957): canalization is developmental Symmetry Protection — developmental trajectories are buffered against perturbation, actively resisting displacement from the organized path. Waddington derived this from embryological observation, entirely independently of Noether’s mathematics.

Maturana and Varela (biology, 1974; 1980): autopoiesis — living systems maintain themselves by producing their own components and boundary. The organized biological state actively resists dissolution through continuous self-production. Three independent fields. Same structural requirement: organized configurations are not passively stable, they are actively protected.

**Hierarchy — Found Independently Four Times**

Simon (complex systems, 1962) found hierarchical composition in every stable complex organization he studied — atoms to molecules to cells to organisms. His observation was empirical: every stable complex system had this property.

O’Neill et al. (ecology, 1986) independently derived hierarchical necessity from ecosystem dynamics: organization results from differences in process rates, with each level having its own controls and stability. A concrete example: a forest canopy operates on a timescale of decades, individual tree growth on years, leaf photosynthesis on hours. Each level has its own characteristic rates and controls. The hierarchical structure emerges from these rate differences — the slower level constrains

and stabilizes the faster one, producing the nested stability Simon identified from the opposite direction.

Parnas (1972) established the same structural requirement from software engineering: complex systems must be decomposed into modules that hide their implementation details from each other, building higher-order functionality on stable lower-level interfaces. Maynard Smith & Szathmáry (1995) found it in evolutionary biology: the major transitions in evolution — from genes to chromosomes, from prokaryotes to eukaryotes, from solitary organisms to colonies — each proceed through the stabilization of a lower level before the next level can emerge. Four communities. Same structural requirement.

No single field found all seven conditions. The pattern across all seven — repeated independent discovery by researchers who were not in contact — is the evidential core of this paper’s argument: these conditions are not a framework someone chose. They kept getting found because they are real properties of organized structure.

## 6. What This Enables

With the seven conditions assembled, a question becomes answerable for any system: does it satisfy all seven? If yes, it is a self-organizing system and inherits the structural properties of that class. If no, the specific condition violated identifies the specific structural weakness. The framework applies to any system claiming to be self-organizing — physical, biological, social, computational. The conditions make the classification testable rather than descriptive.

### IMPLICATION

For any candidate system the question is binary and local: which of the seven fails? The violated condition names the structural weakness.

One application turns out to be particularly testable right now. Gershenson (2025) notes that AI systems may themselves be describable as self-organizing — and cognitive systems are uniquely positioned to test that claim. They are the only class where we can observe both successful operation and failure modes at enormous scale, in real time, with millions of test cases running simultaneously. Whether cognitive systems satisfy the classification, and what the predicted failures look like when they don’t, is examined in the companion paper in this series: Cognition as a Self-Organizing System.

This paper is the foundation it rests on.

*The conditions are not new. Their joint necessity across all classes of self-organizing systems is.*

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## References

1. Ashby, W.R. (1947). Principles of the Self-Organizing Dynamic System. *Journal of General Psychology*, 37(2), 125–128. [doi.org/10.1080/00221309.1947.9918144](https://doi.org/10.1080/00221309.1947.9918144)
2. Ashby, W.R. (1956). *An Introduction to Cybernetics*. Chapman & Hall, London.
3. Bak, P., Tang, C. & Wiesenfeld, K. (1987). Self-organized criticality: An explanation of the 1/f noise. *Physical Review Letters*, 59(4), 381–384. [doi.org/10.1103/PhysRevLett.59.381](https://doi.org/10.1103/PhysRevLett.59.381)
4. Clausius, R. (1850). Über die bewegende Kraft der Wärme. *Annalen der Physik*, 79, 368–397.
5. Clausius, R. (1865). *Annalen der Physik*, 125, 353–400.
6. Conway Morris, S. (2003). *Life's Solution: Inevitable Humans in a Lonely Universe*. Cambridge University Press. ISBN: 0-521-82704-3.
7. Crick, F.H.C. (1958). On Protein Synthesis. *Symposia of the Society for Experimental Biology*, 12, 138–163.
8. Gause, G.F. (1934). *The Struggle for Existence*. Williams & Wilkins Company, Baltimore.
9. Gershenson, C. (2025). Self-organizing systems: what, how, and why? *npj Complexity*, 2(1), Article 10. [doi.org/10.1038/s44260-025-00031-5](https://doi.org/10.1038/s44260-025-00031-5)
10. Haken, H. (1975). Cooperative phenomena in systems far from thermal equilibrium and in nonphysical systems. *Reviews of Modern Physics*, 47(1), 67–121. [doi.org/10.1103/RevModPhys.47.67](https://doi.org/10.1103/RevModPhys.47.67)
11. Haken, H. (1983). *Synergetics: An Introduction*. Springer, Berlin. 3rd ed. ISBN: 978-3-642-88340-5.
12. Hayek, F.A. (1945). The Use of Knowledge in Society. *American Economic Review*, 35(4), 519–530.

13. Kauffman, S.A. (1969). Metabolic stability and epigenesis in randomly constructed genetic nets. *Journal of Theoretical Biology*, 22(3), 437–467. doi.org/10.1016/0022-5193(69)90015-0
14. Kauffman, S.A. (1993). *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford University Press. ISBN: 0-19-507951-5.
15. MacArthur, R.H. & Wilson, E.O. (1967). *The Theory of Island Biogeography*. Princeton University Press. ISBN: 0-691-08836-5.
16. Maturana, H.R. & Varela, F.J. (1974). Autopoiesis: The organization of living systems, its characterization and a model. *Biosystems*, 5(4), 187–196. doi.org/10.1016/0303-2647(74)90031-8
17. Maturana, H.R. & Varela, F.J. (1980). *Autopoiesis and Cognition: The Realization of the Living*. D. Reidel Publishing. ISBN: 90-277-1016-3.
18. Maynard Smith, J. & Szathmáry, E. (1995). *The Major Transitions in Evolution*. Oxford University Press. ISBN: 0-19-850294-X.
19. Nicolis, G. & Prigogine, I. (1977). *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order through Fluctuations*. Wiley-Interscience. ISBN: 0-471-02401-5.
20. Noether, E. (1918). Invariante Variationsprobleme. *Nachrichten der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, 235–257. English translation: Tavel, M.A. (1971). *Transport Theory and Statistical Physics*, 1(3), 183–207.
21. Odum, H.T. (1953). *Fundamentals of Ecology*. W.B. Saunders Company, Philadelphia.
22. O'Neill, R.V., DeAngelis, D.L., Waide, J.B. & Allen, T.F.H. (1986). *A Hierarchical Concept of Ecosystems*. Princeton University Press. (Monographs in Population Biology, 23.)
23. Parnas, D.L. (1972). On the Criteria to Be Used in Decomposing Systems into Modules. *Communications of the ACM*, 15(12), 1053–1058. doi.org/10.1145/361598.361623
24. Poincaré, H. (1890). Sur le problème des trois corps et les équations de la dynamique. *Acta Mathematica*, 13, 1–270.
25. Prigogine, I. (1977). *Time, Structure and Fluctuations*. Nobel Prize Lecture in Chemistry, December 8, 1977. In: Nobel Lectures, Chemistry 1971–1980. World Scientific Publishing, Singapore (1993).
26. Prigogine, I. & Stengers, I. (1984). *Order Out of Chaos: Man's New Dialogue with Nature*. Bantam Books, New York. ISBN: 0-553-34082-4.
27. Schelling, T.C. (1978). *Micromotives and Macrobehavior*. W.W. Norton & Company, New York. ISBN: 978-0-393-32946-9.
28. Shannon, C.E. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal*, 27(3), 379–423; 27(4), 623–656. doi.org/10.1002/j.1538-7305.1948.tb01338.x
29. Simon, H.A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society*, 106(6), 467–482. JSTOR: 985254.

30. Strogatz, S.H. (1994). *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*. Perseus Books, Cambridge MA. (3rd ed. CRC Press/Routledge, 2018. ISBN: 978-0-367-02650-9.)
  31. Turing, A.M. (1952). The Chemical Basis of Morphogenesis. *Philosophical Transactions of the Royal Society of London B*, 237(641), 37–72. [doi.org/10.1098/rstb.1952.0012](https://doi.org/10.1098/rstb.1952.0012)
  32. Waddington, C.H. (1957). *The Strategy of the Genes: A Discussion of Some Aspects of Theoretical Biology*. Allen & Unwin, London.
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